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A METHOD OF ESTIMATING THE AERODYNAMIC EFFECTS OF ORDINARY AND SPLIT FLAPS OF AIRFOILS SIMILAR TO THE CLARK Y

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SUMMARY

An empirical method is given for estimating the aerodynamic effect of ordinary and split flaps on airfoils similar to the Clark Y. The method is based on a series of charts that have been derived from an analysis of existing wind-tunnel data. Factors are included by which such variables as flap location, flap span, wing aspect ratio, and wing taper may be taken into account. A series of comparisons indicate that the method would be suitable for use in making preliminary performance calculations and in structural design.

INTRODUCTION

In order to improve the speed range of airplanes it is customary to use some sort of high-lift device. At present the use for this purpose of either the ordinary flap or some modification of the simple split flap is almost universal. Although the results of numerous experiments for wings with flaps exist, little attempt has been made to analyze the data as a whole except in a qualitative way. The present note is intended to summarize available data on the ordinary and split types of flap in such form that it may be readily used in estimating the characteristics of airfoils equipped with flaps.

SCOPE OF THE METHOD

As the results have been derived principally from tests made in the N.A.C.A. 7- by 10-foot wind tunnel on the Clark Y airfoil, it is expected that the method will give the best results when applied to similar airfoils. Results from tests of other airfoils have been included in several cases in order to derive factors by which modifications of the flap arrangement may be taken into account.

The analysis given herein holds only for the range between maximum negative and maximum positive lift. In this range the effect of flap displacement on the wing lift, drag, and pitching-moment coefficients as well as on the variation of the flap-lift and hinge-moment coefficients is covered. The types of flap considered are the plain trailing-edge, or ordinary, flap and the split trailing-edge flap. Variations of the latter type of flap occur as the pivoting point moves along the lower surface of the wing section.

The sources of the data considered in the analysis and the important geometric characteristics of the wings tested are given in table I. All tests were made with wings of aspect ratio 6 and without gap or balancing area. Only those tests in which the ratio of the flap to the wing chord was constant on the portion of the wing equipped with flaps were used in the analysis although factors for taking into account other slight variations are given. Wherever possible the results have been plotted in a form that permits comparisons with the existing flap theory to be readily made. Unpublished data have been used in several instances; hence the results are based on more tests than would at first appear.

SYMBOLS

C_L, total lift coefficient of wing with flap deflected.

C_{L_w}, lift coefficient of portion of wing with flaps.

C_{L_o}, lift coefficient for zero flap deflection.

ΔC_L, lift increment due to full-span flaps.

a, slope of lift curve, per degree.

a_6, slope of lift curve for aspect ratio 6, per degree.

α, angle of attack of plain wing from zero lift, degrees.

δ_f, flap angle, degrees.

k, theoretical rate of change of α with δ_f.

K_1, proportion of total wing area equipped with flaps.

K_2, ratio of mean wing chord of portion equipped with flaps to the mean geometric chord of the wing.

F_1, span-location factor for lift.

F_2, aspect-ratio factor.

F_3, span-location factor for pitching moment.

R, wing aspect ratio.

$\frac{x}{c}$, hinge location in fractions of chord from leading edge of wing.

E, ratio of flap chord to wing chord c_f/c_w.

C_D, total drag coefficient of wing with flap.

C_{D_i}, induced-drag coefficient.

$C_{D_{o_{min}}}$, minimum drag coefficient for plain airfoil.

ΔC_{D_o}, increase in profile drag above $C_{D_{o_{min}}}$.

$\Delta C_{D_{o_{min}}}$, increment added to $C_{D_{o_{min}}}$ due to flap deflection.

C_m, total pitching-moment coefficient about quarter-chord point of the mean chord with flaps deflected.

C_{m_o}, pitching-moment coefficient about quarter-chord point for plain airfoil.

ΔC_m, increment of pitching-moment coefficient about quarter-chord point due to full-span flaps.

m, theoretical rate of change of pitching-moment coefficient with δ_f.

$C_{L_{f_o}}$, flap lift coefficient at $\alpha = 0$.

C_{L_f}, flap lift coefficient.

n_o, theoretical rate of change of C_{L_f} with C_{L_w}.

n, theoretical rate of change of C_{L_f} with δ_f.

C_{h_f}, flap hinge-moment coefficient.

$C_{h_{f_o}}$, flap hinge-moment coefficient at $\alpha = 0$.

h_o, theoretical rate of change of C_{h_f} with C_{L_w}.

h, theoretical rate of change of C_{h_f} with δ_f.

λ, ratio of tip to root chord.

EFFECT OF FLAP ON LIFT

According to theory (reference 1) the lift coefficient of an airfoil with an ordinary flap* is given by the expression

$$C_L = a\alpha + ak\delta_f \tag{1}$$

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*As used in the present report an "ordinary flap" is simply the portion formed by hinging the trailing edge of an airfoil about a point in the airfoil so that no gap is formed as the flap is deflected. A simple "split flap" is formed when the trailing edge of an airfoil is split and the lower surface is deflected downward with no movement of the hinge point in a chordwise direction.

As no theory exists for an airfoil with a split flap, equation (1) has been changed to the similar form

$$C_L = C_{L_0} + F_1 F_2 K_1 \Delta C_L \qquad (2)$$

in which $F_1 F_2 K_1 \Delta C_L$ is the part representing the increase in C_L due to the flaps. It is obvious that the final value of the increase in C_L may depend, in the case of an ordinary flap, upon a combination of several variables: flap angle δ_f, flap chord ratio E, angle of attack α, portion of wing equipped with flaps K_1, flap location along the span, wing aspect ratio R, wing taper λ, and possibly others. In the case of split flaps, the hinge position x/c along the wing chord introduces an additional variable. When summarizing the data, the effects of the foregoing variables were taken into account.

The ΔC_L of equation (2) is the increase in the total wing C_L that would occur with a full-span flap on a wing of aspect ratio 6. These values of ΔC_L, obtained from data given in reference 2 for the Clark Y wing, are given in figure 1 for the ordinary flap. In order to enable these increments to be applied to other airfoils, they are plotted against the absolute angle of attack of the plain airfoil section, with the flap chord ratio and flap angle as parameters. Similarly, values of ΔC_L for the simple split flap were obtained from the data given in references 2, 3, 4, 5, and 6. The final weighted curves are shown in figure 2. These two figures are considered to be the basic lift-increment curves.

For split flaps in which the hinge location is either forward or back of the simple split-flap position a set of increments similar to those of figure 2 would be required for the various flap positions along the wing chord. In order to limit the number of figures a series of conversion factors (figs. 3(a), 3(b), and 3(c)) are given. The factor of figure 3(a) converts the actual flap system into an equivalent simple split-flap system so that it becomes possible to use figure 2 and to find the lift increments at the new value of E. This lift-increment factor was determined by comparing the values of ΔC_L, obtained from the data given in references 3 and 7 in which the hinge location was varied, with the values of ΔC_L for simple split flaps.

If a partial-span flap is used in conjunction with a wing of different aspect ratio, the basic ΔC_L values must be modified by various factors. The first is the proportionality factor K_1, defined as the proportion of the total wing area equipped with flaps. Such a factor is suggested by the fact that it would be natural to assume that if only half of the wing area had flaps only half of the increments given in figures 1 and 2 would be realized. This assumption is, however, true only for certain cases, and consequently a span-location factor F_1 is necessary. This factor was obtained from an analysis of the data given in references 4 and 6 in which the effect of partial-span split flaps on both rectangular and tapered wings was reported. The different lengths and locations of the flaps were obtained by cutting off portions of a full-span flap first from the tips and then from the center. Although this factor was derived entirely from tests of simple split flaps set at 60°, there is good reason to believe that it will hold for other flap angles and for the ordinary flap. The location factor is shown in the lower half of figures 1 and 2 plotted against the centroid of the flap, measured from the wing center line, in terms of the wing semispan. The curves for tapers between 1.0 and 0.2 have been interpolated because no data exist for intervening taper ratios.

Although no tests are available of wings with flaps for aspect ratios greater than 6, an aspect-ratio correction factor F_2 is necessary since the increase in C_L of equation (2) is analogous to the $ak\delta_f$ of (1) in which a varies with the aspect ratio. This factor is, from the nature of the analysis, unity at aspect ratio 6. For other aspect ratios it has been computed from the modified theoretical formula

$$\frac{a}{a_6} = \frac{2\pi}{57.3a_6}\left(\frac{1}{1 + \frac{2}{R}}\right) \qquad (3)$$

This factor is also plotted in figures 1 and 2.

The average lift coefficient for only the portion of the wing having flaps C_{L_w}, from the method used in analyzing the data, is obtained by dropping the factor K_1 in equation (2). This lift coefficient is necessary to compute the flap lift and hinge-moment coefficients.

EFFECT OF FLAP ON DRAG

In the case of drag, airfoil theory provides for the computation only of the induced part, which is given by the equation

$$C_{D_i} = \frac{C_L^2}{\pi R} (1 + \sigma) \tag{4}$$

where σ is a factor correcting the induced drag to allow for changes from the elliptical span loading. For ordinary airfoils it is customary to consider that the remainder of the drag coefficient consists of two parts; one, $C_{D_{o_{min}}}$, the minimum drag coefficient and the other, ΔC_{D_o}, the increase in profile drag above $C_{D_{o_{min}}}$. The latter may be dependent upon camber, thickness, and $C_{L_{opt}}$, the wing C_L at $C_{D_{o_{min}}}$. Several empirical expressions exist for this increase but, as they do not agree with the data on airfoils with flaps, they will not be given.

For airfoils with flaps, the same division of drag is made and, in addition, a new term $\Delta C_{D_{o_{min}}}$ is introduced. This term represents the increase in minimum drag due to flap deflection. These increments are given in figures 4 and 5 for full-span ordinary and simple split flaps, respectively. The numerical values for $\Delta C_{D_{o_{min}}}$ were obtained mainly from an analysis of the data previously referred to in the discussion of the curves for the lift increments.

The increase in the profile-drag coefficient above $C_{D_{o_{min}}}$ for wings with full-span flaps with a constant flap chord ratio can be given approximately by

$$\Delta C_{D_o} = 0.016 \, (C_L - 0.2)^2 \tag{5}$$

This expression holds reasonably well at lift coefficients below 1, but from that point to the stall of the particular combination being investigated it is at best only an average of quite widely scattering points.

The induced drag for wings with full-span flaps of constant flap chord ratio is given by equation (4) where σ may usually be omitted, as it is small. If wings with partial-span flaps or with varying flap chord ratios are used, however, σ may become quite large. For a given case its magnitude may be theoretically determined but the determination would entail considerable labor, which ordinarily would not be justified. Lacking the correct value of σ for these cases, the value of C_{D_i} can be determined only approximately by the usual methods. In order to serve as a guide, the value of $C_{D_i} + \Delta C_{D_o}$ obtained by the addition of equations (4) and (5) is plotted in figures 4 and 5 for several aspect ratios.

The only modifying factor included in the drag expression is the previously found proportionality factor K_1. Introducing this factor, the total drag coefficient for the wing with either the ordinary or the simple split flap is given by

$$C_D = C_{D_i} + \Delta C_{D_o} + C_{D_{o_{min}}} + K_1 \, \Delta C_{D_{o_{min}}} \tag{6}$$

The values of $\Delta C_{D_{o_{min}}}$ as given by figures 4 and 5 may be considered to be section increments of profile drag.

As in the case of the lift increments, the effect of different hinge locations of the split flap is taken care of by correcting to an equivalent simple split flap before determining $\Delta C_{D_{o_{min}}}$ from figure 5. These conversion factors, which were obtained from the data given in references 3 and 7 by a simple comparison with the $\Delta C_{D_{o_{min}}}$ values for the simple split flap, are shown in figure 3(b).

EFFECT OF FLAP ON PITCHING MOMENT

The theoretical pitching-moment relation for an airfoil with an ordinary flap is

$$C_m = C_{m_o} + m\delta_f \tag{7}$$

and, proceeding as before, this equation may be written in a similar form

$$C_m = C_{m_o} + K_1 K_2 F_3 \Delta C_m$$

where $K_1 K_2 F_3 \Delta C_m$ is the increase in the pitching moment due to the flaps. For the ordinary flap the effect of the following variables on the increase in C_m has been determined: flap angle, flap chord ratio, portion of wing equipped with flaps, flap location along the span, wing lift, and wing taper. In the case of the split flap the effect of the hinge position along the wing chord has also been determined.

The ΔC_m of equation (8) is the increase in C_m that would occur with a full-span flap on a wing of aspect ratio 6. Its values for the ordinary flap were obtained from data given in reference 2, supplemented by some unpublished results. Plots of ΔC_m against the wing-lift coefficient, with flap angle and flap chord as parameters, showed ΔC_m to be practically independent of flap chord ratio (i.e., $E = 0.1$ to 0.4) for a given flap deflection and to depend mainly upon the flap angle and the value of C_L. The final averaged curves for the ordinary flap are given in figure 6. A similar procedure was followed for the simple split flap using the data given in references 3, 4, and 5. The final curves for ΔC_m are given in figure 7.

For split flaps in which the hinge position is different from the simple split-flap position, a conversion factor has been derived. As the pitching moment was found to be independent of E, the effect of varying the hinge position along the wing chord could not be taken into account by correcting to an equivalent simple split flap as was done for the lift and drag. Using the data of reference 3, in which the hinge line was moved rearward, the values of ΔC_m were plotted against C_L for various flap angles and for various flap chord ratios. It was noted that the percentage increase in the pitching-moment increment over that of a simple split flap at an equal flap angle and for a given backward movement of the hinge point was practically the same. The variation of this factor is shown in figure 3(c).

The curves given in figures 6 and 7 have been derived for full-span flaps. If partial-span flaps are used, a proportionality and a location factor must be introduced. The proportionality factor K_1 is the same as that used in the lift and drag expressions. The location factor K_3 for pitching moment has been derived entirely from reference 4 by assuming that such a factor existed and by working backward through the data given there to determine its value. This factor, although derived from data on simple split flaps, is assumed to hold for ordinary flaps and for other modifications of the split flap.

For tapered wings in which the rib aerodynamic centers across the span lie on an unbroken straight line, an additional factor K_2 (defined in list of symbols) must be introduced to obtain the total pitching-moment coefficient about the quarter-chord point of the mean geometric chord. Introducing this factor, the expression for pitching moment can be given very nearly by equation (8). For tapered wings in which the rib aerodynamic centers lie on a curved or broken line, formula (8) would hold if the load distribution were such that it produced no pitching moment about the quarter-chord point of the mean geometric chord. A better method would be to assume the ΔC_m values of figures 6 and 7 to be section characteristics and to integrate across the span for the total pitching-moment coefficient about the desired point. Such a procedure would require that the distribution of C_L along the span be known.

Although the data of reference 7 were not directly used in establishing figure 7, they served, nevertheless, to confirm the fact that the hinge moment at a given value of the wing lift and flap angle was practically the same for the different hinge locations (x/c) of the split flaps reported therein.

HINGE MOMENT OF FLAP

The hinge-moment coefficient is probably the most important of the flap coefficients for it must be known in order to design the control mechanism of the flap. Theoretically it is given by the formula

$$C_{h_f} = h_o\, C_{L_w} - h\delta_f - C_{h_{f_o}} \qquad (9)$$

The data on the variation of this coefficient for the ordinary flap are limited to those given in references 2 and 8 and for simple split flaps to those in references 5 and 7. In references 7 and 8 the data, regarded as giving mainly qualitative results, were obtained from pressure-distribution tests on single ribs. The first step in the analysis of the hinge moment was to base the coefficients, where necessary, on the flap chord and the flap area rather than on the wing chord and the wing area, as had been done in some cases. These values were then plotted against the wing lift coefficient for each flap chord ratio and each flap angle. A comparison of the data on the two types of flap led to the conclusion that the hinge-moment coefficient is almost the same for both the ordinary and simple split flap and that it is, for practical purposes, independent of flap chord ratio. The final faired curves are given in figure 8. Values of C_{h_f} are plotted against C_{L_w} instead of C_L since with partial-span flaps the hinge moment depends upon the lift on that portion of the wing over which the flap extends rather than upon the lift of the whole wing.

LIFT ON FLAP

The flap lift coefficient for an airfoil with an ordinary flap is given theoretically by

$$C_{L_f} = n_o\, C_{L_w} - n\delta_f + C_{L_{f_o}} \qquad (10)$$

The data on the variation of this coefficient are at present very meager, being limited to those given in references 5 and 7 for simple split flaps and to those in reference 8 for ordinary flaps.

For the simple split flaps, both sets of data agree in showing that the rate of change of C_{L_f} with C_{L_w} decreases practically to zero as C_{L_f} becomes fairly large. The two references do not, however, show the same magnitude of C_{L_f} for similar flap angles but differ by amounts not exceeding 0.2. The flap loads in reference 8 were given more weight in obtaining the curves of figure 9 because they were obtained by direct measurements. The data of reference 7 served, however, to establish the conclusion that the lift on the split flap for equal flap angles and flap chord ratios may be considered as invariable with hinge location when compared on the basis of equal values of C_{L_w}. By the use of a value of C_{L_w} instead of C_L, the effect of partial-span flaps may be estimated.

The ordinary (reference 8) and split-flap data indicate that the flap lift may be considered the same for both types. It must be remembered, however, that this conclusion is based on a single comparison between a pressure-distribution test over a single rib and a series of force tests.

DISCUSSION OF CHARTS

A comparison of figures 1 and 2 will show that the lift increments for ordinary and split flaps are not appreciably different. At the high angles of attack the lift increments of the split flaps tend to be slightly higher than those of the ordinary flaps, inferring a somewhat higher maximum lift. At the low angles of attack, particularly for low flap deflections, the lift increments for the ordinary flap tend to be larger than those for the split flap.

The lift increments, in general, increase with flap angle and flap chord but do not follow any general law for variation with angle of attack. At the angle of attack corresponding to $C_{L_{max}}$ of the wing with undeflected flaps, the lift increments become smaller with increasing flap chord ratio and flap angle.

For airfoils not similar to the Clark Y in thickness and camber the lift increments do not apply although the method could be used provided that suitable lift-increment charts were available. Qualitatively, the effect of increasing the camber should be to decrease the lift increments for a given angular movement of the flap, since the true flap displacement should probably be measured from the zero lift direction of the plain airfoil section.

When the lift increments for the N.A.C.A. 23021 (reference 2) were compared with those given in figures 1 and 2, it was obvious that the effect of thickness was, in this case, to increase the lift increments considerably at the large angles of attack and to decrease them at the small angles. If flaps of short chord were used on thick airfoils, however, the effect of the flap would probably be partly masked by the effect of the boundary layer. The location factors (figs. 1 and 2) show, as would be expected, that when partial-span flaps are used on nearly rectangular wings, they are most advantageously placed near the center line.

It will be noted that even though for the highly tapered wing the location factor indicates a higher unit loading when the flaps are placed near the tips, the increase in location factor is not sufficiently rapid to compensate for the decrease in the area affected by the flap. The conversion factor (fig. 3(a)) indicates that, for a given flap chord and angle, larger increments of lift occur as the split flap is moved backward and smaller ones as it is moved forward.

Recent tests have shown that the lift increments may be considered to be independent of Reynolds Number. Thus, it is possible to apply these results in computing the lift characteristics of the full-scale airplane, or wing with flaps, provided that the lift curve for zero flap deflection is known.

The $\Delta C_{D_{o_{min}}}$ curves indicate that a slightly lower drag would be obtained throughout the lift range with the ordinary flap than with the simple split flap. The conversion factors for drag on split flaps (fig. 3(b)) indicate that moving the split flap rearward tends to decrease the minimum drag; whereas moving it forward increases it. This variation has been inferred in several other publications.

The pitching-moment curves (figs. 6 and 7) show that the ΔC_m values obtained with plain flaps at low lifts are higher than those for the simple split flap and that at high lifts this difference approaches zero. The location-factor curves for pitching moment show that, over most of the range, the value of the location factor is unity and may, in many cases, be neglected. On the other hand, the conversion-factor curve for split flaps shows a tremendous increase in pitching-moment coefficient about the original quarter-chord point as the hinge point is moved backward. The pitching-moment increments of figure 7 in the case of a 20-percent-chord flap moved back to the 90-percent-chord point are 45 percent larger than those for a similar simple split flap. Conversely, moving the flap forward decreases the increments, although sufficient data are not available to establish definitely the dotted portion of figure 3(c).

ACCURACY

All the experimental points have been omitted from the charts for the sake of clarity. In order to gage the accuracy of the charts and the method, however, several figures comparing the computed and experimental airfoil characteristics are included. Comparisons are made of the lift, drag, and pitching-moment coefficients where possible.

Figure 10 compares the computed and observed characteristics for a simple split flap on a Clark Y airfoil. Since the experimental data given in this figure were used in deriving the lift-increment chart, a good agreement was to be expected. Similar comparisons are not given for the ordinary flap because the same variation between the computed and experimental values would appear.

A truer idea of the discrepancies to be expected in applying the method is gained from figure 11 in which the effects of different airfoil sections as well as the differences obtained from tests in various tunnels are represented. In some cases tests were made of a full-scale airplane; others are tests of model wings at different values of the Reynolds Number.

Similar comparisons of the ordinary flap and of other chordwise positions of the split flap agree as well except when the hinge point is moved to coincide with the trailing edge. In this case the conversion factors of figure 3(a) do not hold. The agreement for highly tapered wings is good throughout most of the lift range except at the stall where it is noted (reference 6) that the angle of maximum lift decreases with increase in flap angle. For rectangular wings, and presumably for those with small taper, the angle of maximum lift with flaps deflected is the same as for the plain airfoil so that no reduction in angle of attack is necessary in order to gage the maximum-lift coefficient. In the application of this method to compute the characteristics of highly tapered wings with flaps some estimate must be made of the decrease in the angle of maximum lift with flap angle. At present reference 6 is the only source that furnishes any data on this point.

Figure 12 gives the data on the hinge moments of full-span ordinary and simple split flaps. The different airfoils, flap chord ratios, and flap angles are indicated in figure 12 and the curves of figure 8 are included for comparison.

Consideration of the range covered by the comparisons shows that these charts may be used to give a reasonable estimate of the effects of flaps on the airfoil characteristics. Although the absolute values of the increments may change as more data are obtained, the method used herein is convenient for purposes of analysis as a comparison may be easily made with the results of flap theory.

USE OF THE CHARTS

In order to illustrate the use of the charts in the determination of the aerodynamic characteristics of an airfoil with flaps the following example is included.

Given: Wing of plan form and flap dimensions as shown in figure 13 with N.A.C.A. 2212 airfoil section. In order to apply the method it is assumed that the C_{L_0} and C_{m_0} curves are given and that $C_{D_{0_{min}}}$ is known.

To find: The characteristics of the complete wing and the flap coefficients at an angle $2\frac{1}{2}^{\circ}$ below the stall angle of the plain wing when the flap is deflected 45°.

Solution:

Absolute angle of attack of basic section at desired angle, 20°.

Lift coefficient at 20° absolute angle of attack, 1.5.

Minimum-drag coefficient with no flaps, 0.009.

C_{m_0} at 20° absolute angle of attack, -0.03.

K_1, 0.583 (by computation).

K_2, 1.166 (by computation).

F_1, 1.00 (fig. 2 for taper = 0.5 and centroid at 0.476).

F_2, 1.03 (fig. 2, for $R = 7$).

F_3, 1.00 (fig. 7).

Equivalent simple split flap for lift increments with hinge point 10 percent c forward of simple position, $E = 0.195$ (fig. 3(a)).

Equivalent simple split flap for drag, $E = 0.28$ (fig. 3(b)).

Pitching-moment factor, 0.7 (fig. 3(c)).

Lift increment (for $E = 0.195$, $\delta_f = 45^\circ$), 0.68 (fig. 2).

$$C_L = C_{L_o} + K_1\ F_1\ F_2\ \Delta C_L$$

$$= 1.5 + (0.583 \times 1.0 \times 1.03 \times 0.68) = 1.91$$

Drag increment (for $E = 0.28$, $\delta_f = 45^\circ$), 0.155 (fig. 5).

$$C_D = \left(C_{D_i} + \Delta C_{D_o}\right) + C_{D_{o_{min}}} + \left(K_1\ \Delta C_{D_{o_{min}}}\right)$$

$$= (0.217) + 0.009 + (0.583 \times 0.155) = 0.317$$

Pitching-moment increment for $\delta_f = 45^\circ$ and at a value of $C_{L_w} = 2.20$, obtained from $1.5 + (1.0 \times 1.03 \times 0.68)$, −0.212 (fig. 7).

$$C_m = C_{m_o} + K_1\ K_2\ F_3\ \Delta C_m \times \text{pitching-moment factor}$$

$$= -0.03 + (0.583 \times 1.166 \times 1.0 \times -0.212 \times 0.7) = -0.131$$

Hinge-moment coefficient for $\delta_f = 45^\circ$ and $C_{L_w} =$ 2.23, −0.543 (fig. 8).

$$\text{Hinge moment} = C_{h_f}\ qS_f\ c_f$$

$$= -0.543 \times qS_f\ c_f$$

where S_f is the area of the flap and q is the dynamic pressure.

Flap lift coefficient for $\delta_f = 45^\circ$, $E = 0.25$ and at $C_{L_w} = 2.23$, 1.3 (fig. 9).

Load on flap = $C_{L_f} q S_f = 1.3\ q S_f$

The foregoing procedure could be repeated for other angles and hinge positions to obtain a complete solution.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 16, 1935.

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TABLE I

Summary of Reference Data

Source	Airfoil section	Taper λ	E c_f/c_w	Flap span, percent b	Flap angle, δ_f, degrees	Hinge location, percent chord	Data given for[1]				Remarks
					Ordinary flaps						
Reference 8	RAF-30	1.0	0.10 .20	2)	10,20,30, 40,50	90 80	C_{m_0}	C_m	C_{h_f}	C_{L_f}	Pressure distribution
Reference 2	Clark Y	1.0	0.10 .20 .30	100	15,30,45, 60	90 80 70	C_{m_0}	C_m	C_{h_f}	—	Force tests on model wing R.N. 609,000
	N.A.C.A. 23012	1.0	0.20	100	15,30,45, 60	80	C_{m_0}	C_m	C_{h_f}	—	
	N.A.C.A. 23021	1.0	0.20	100	15,30,45, 60	80	C_{m_0}	C_m	C_{h_f}	—	
3)	N.A.C.A. 2212	1.0	0.18	100	15,30,45, 60	82	C_{m_0}	C_m	C_{h_f}	—	
					Split flaps						
Reference 7	N.A.C.A. 2212	1.0	0.10 .20 .30	88.5	20,40,60 10,20,40,60 20,40	70,80,90	—	—	C_{h_f} 2)	C_{L_f} 2)	Force tests on F-22 airplane
Reference 3	Clark Y	1.0	0.20 .30 .40	100	15,30,45, 60	80,90,100 70,80,90,100 60,70,80,90,100	—	—	—	—	
Reference 4	Clark Y	1.0	0.20	100 80 60 40 20	60	80	C_{m_0}	C_m	—	—	
Reference 5	Clark Y	1.0	0.15 .25	100	15,30,45,60 15,30,45	85 75	C_{m_0}	C_m	C_{h_f}	C_{L_f}	Force tests on model wing R.N. 609,000
Reference 6	Clark Y	0.2	0.25 .15	100 100 80 60 40 20	15,30,45,60,75 15,30,45,60 60	75 85	C_{m_0}	C_m	—	—	
3)	N.A.C.A. 2212	1.0	0.15	100	15,30,45, 60	85	C_{m_0}	C_m	C_{h_f}	—	

[1] All sources give values of C_L, C_{L_0}, C_D, and $C_{D_{0_{min}}}$.

[2] Results from pressure-distribution tests on single rib.

[3] Unpublished.

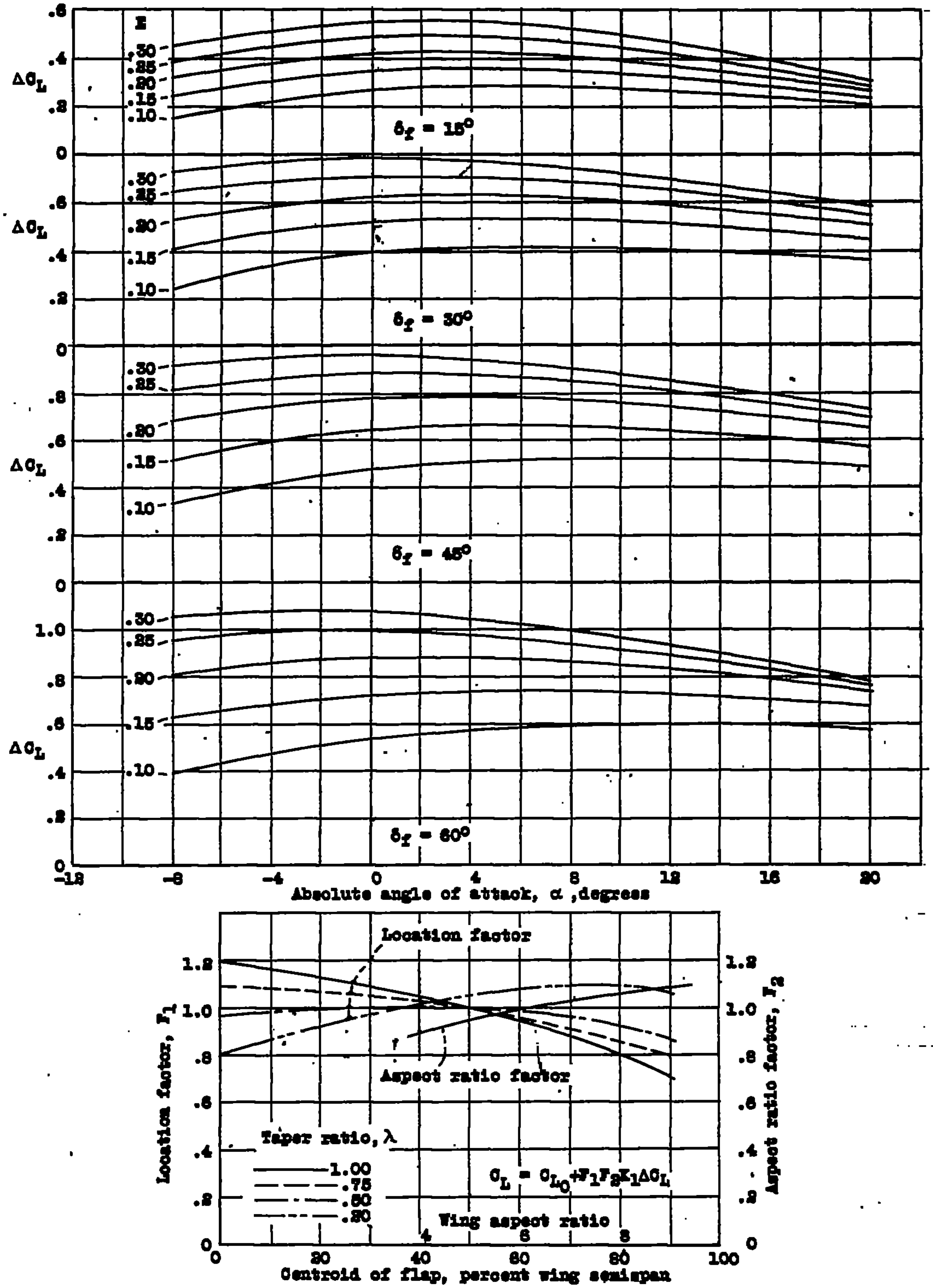


Figure 1.- Lift increments for ordinary flaps.

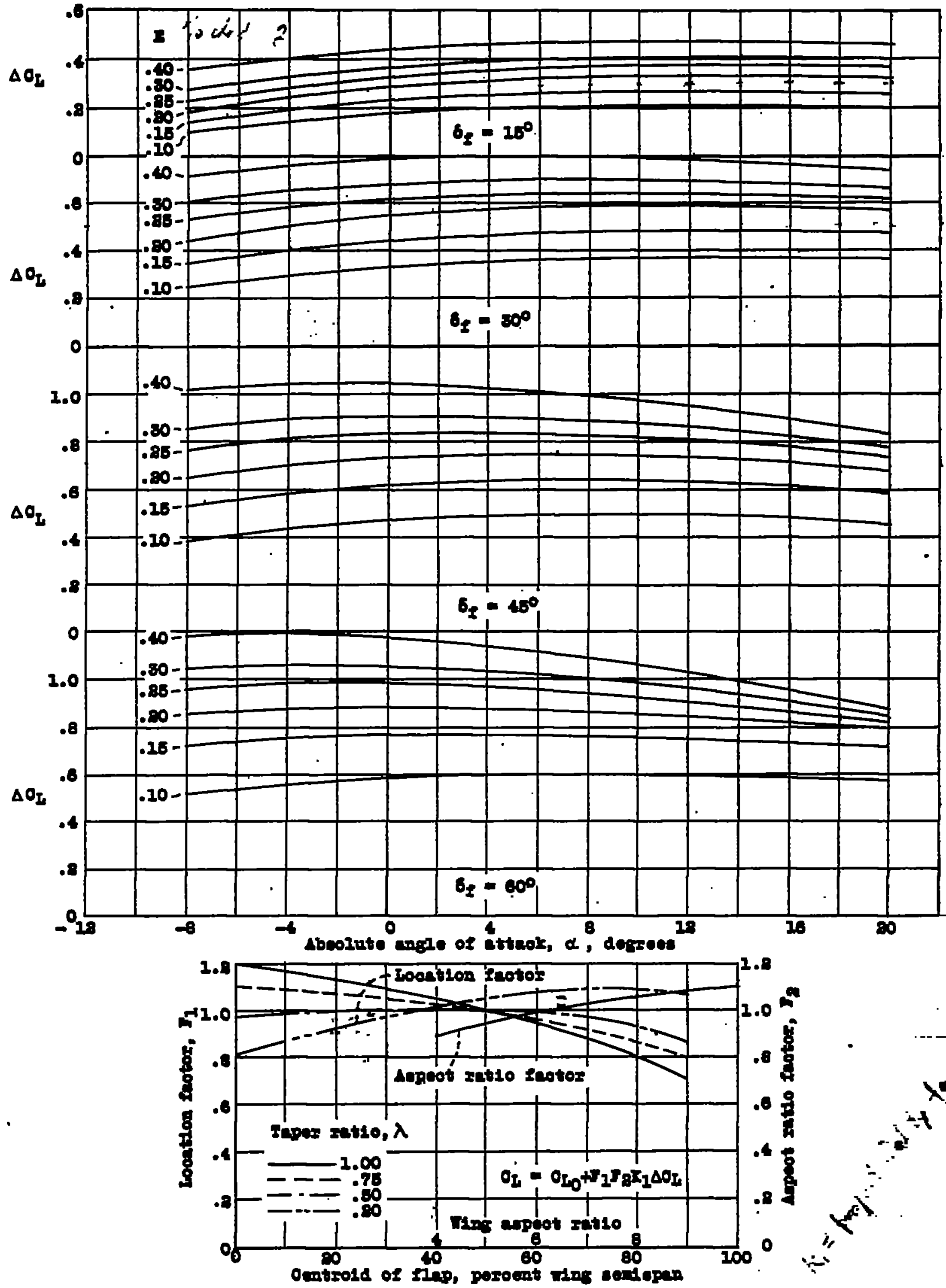


Figure 2.- Lift increments for simple split flaps.

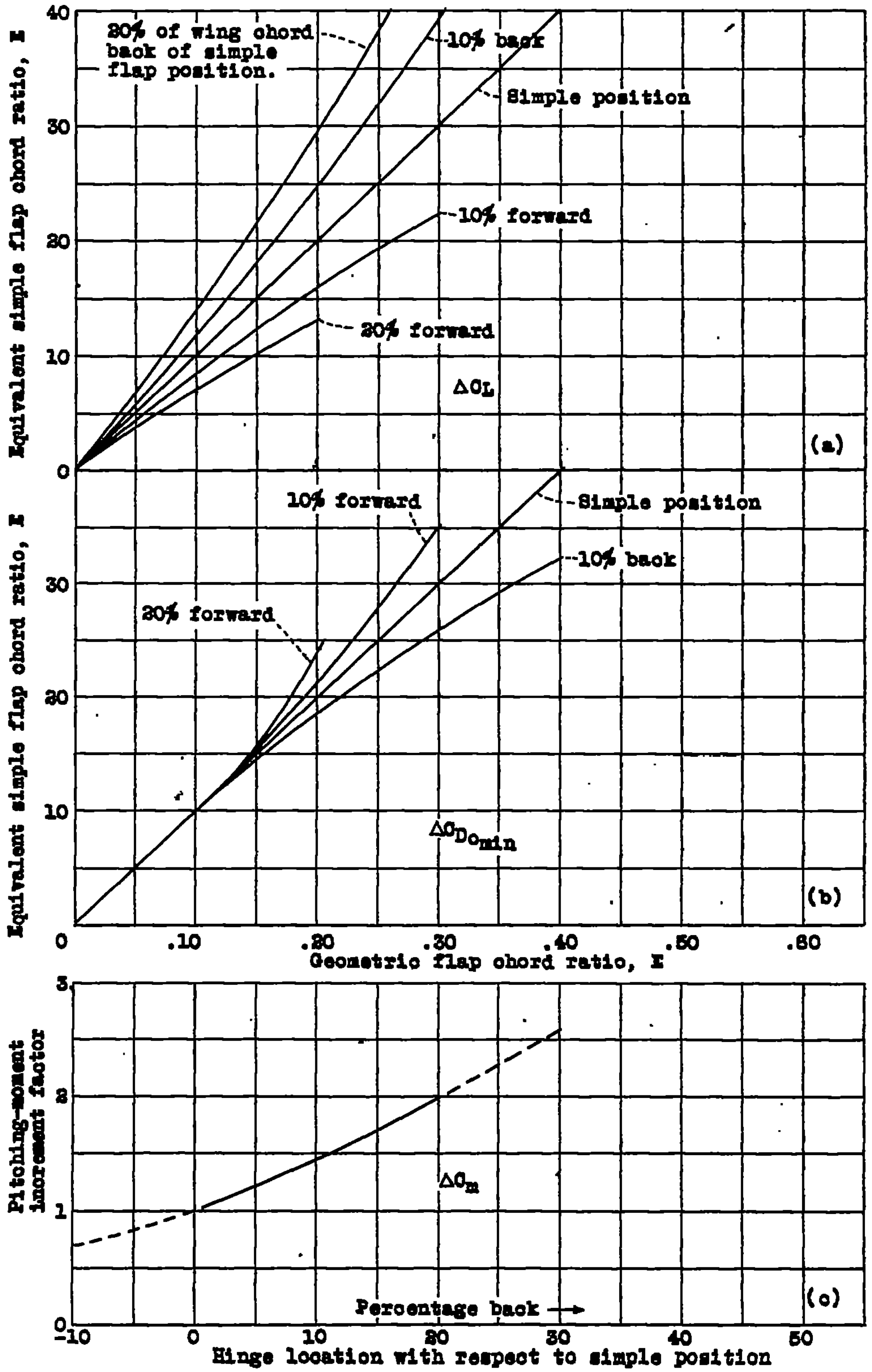
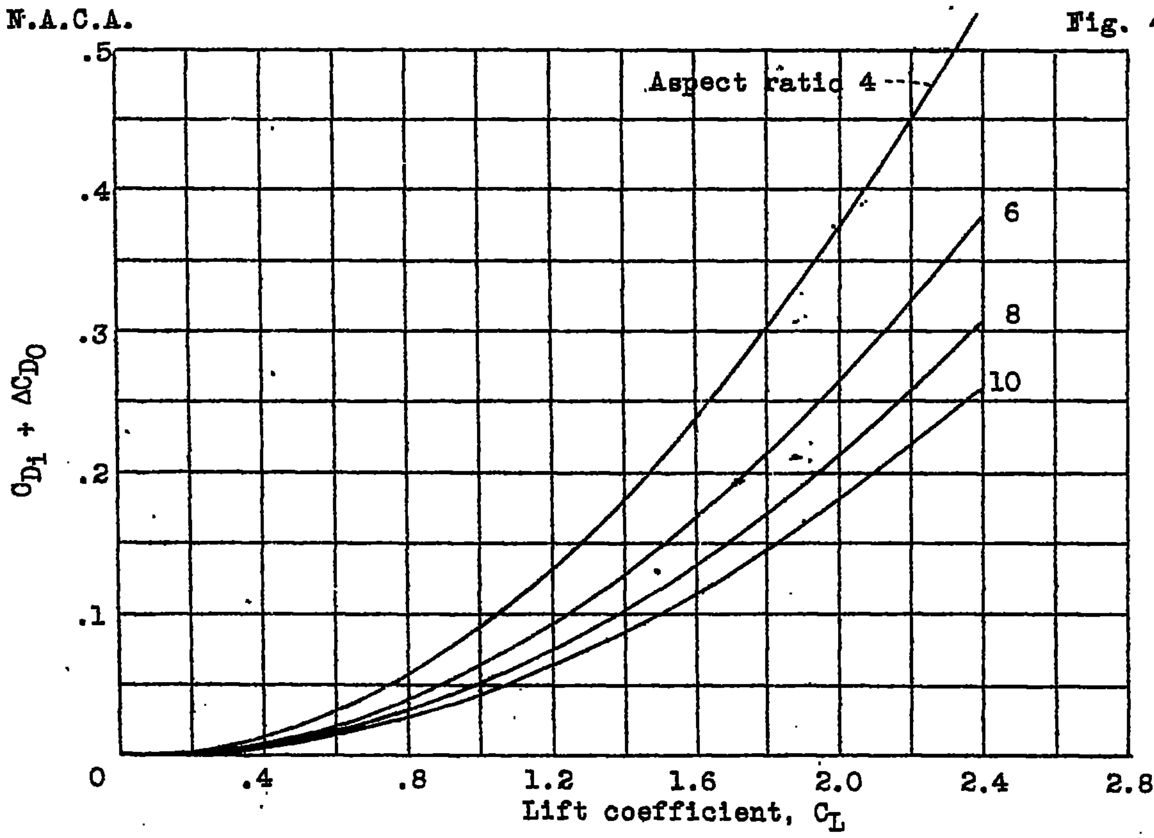


Figure 3.- Conversion factors for lift, drag and pitching-moment coefficients.



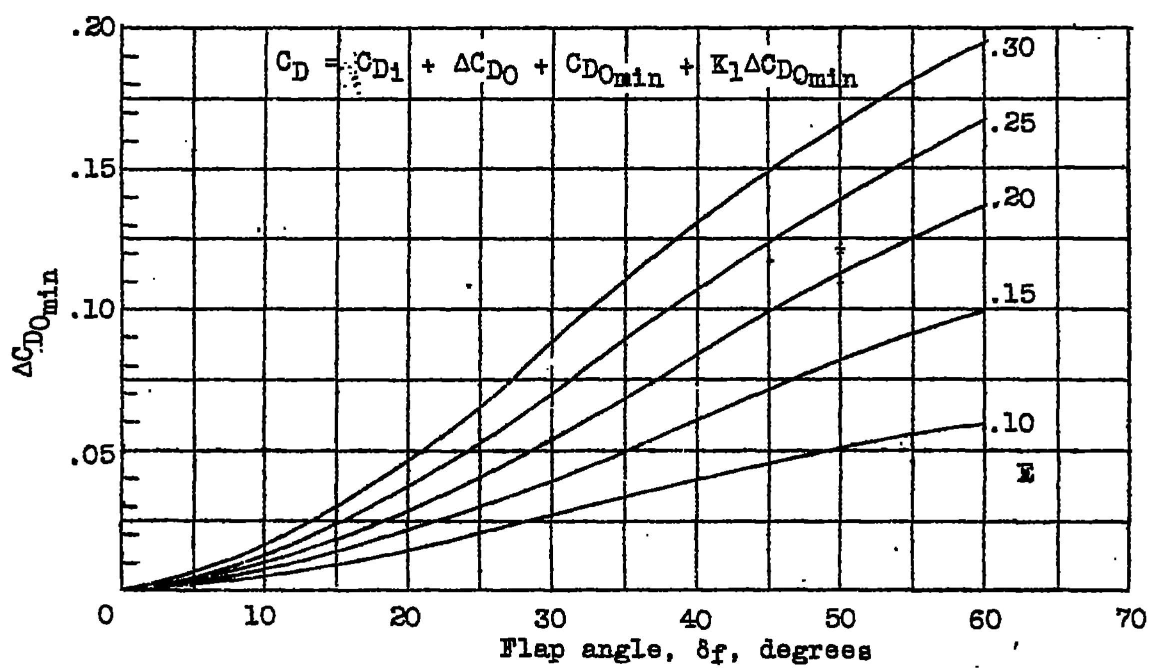


Figure 4.- Drag increments for ordinary flaps.

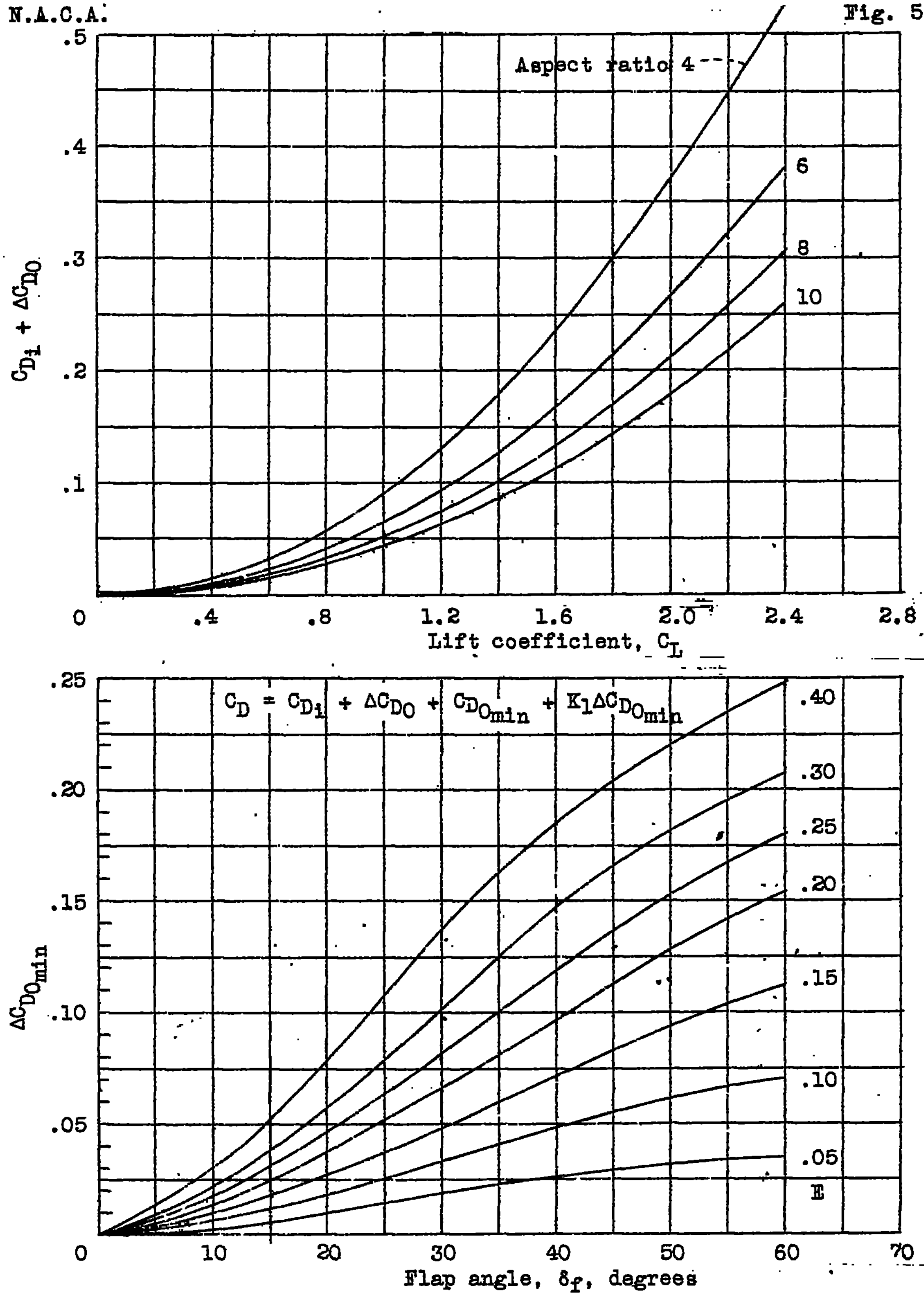


Figure 5.- Drag increments for simple split flaps.

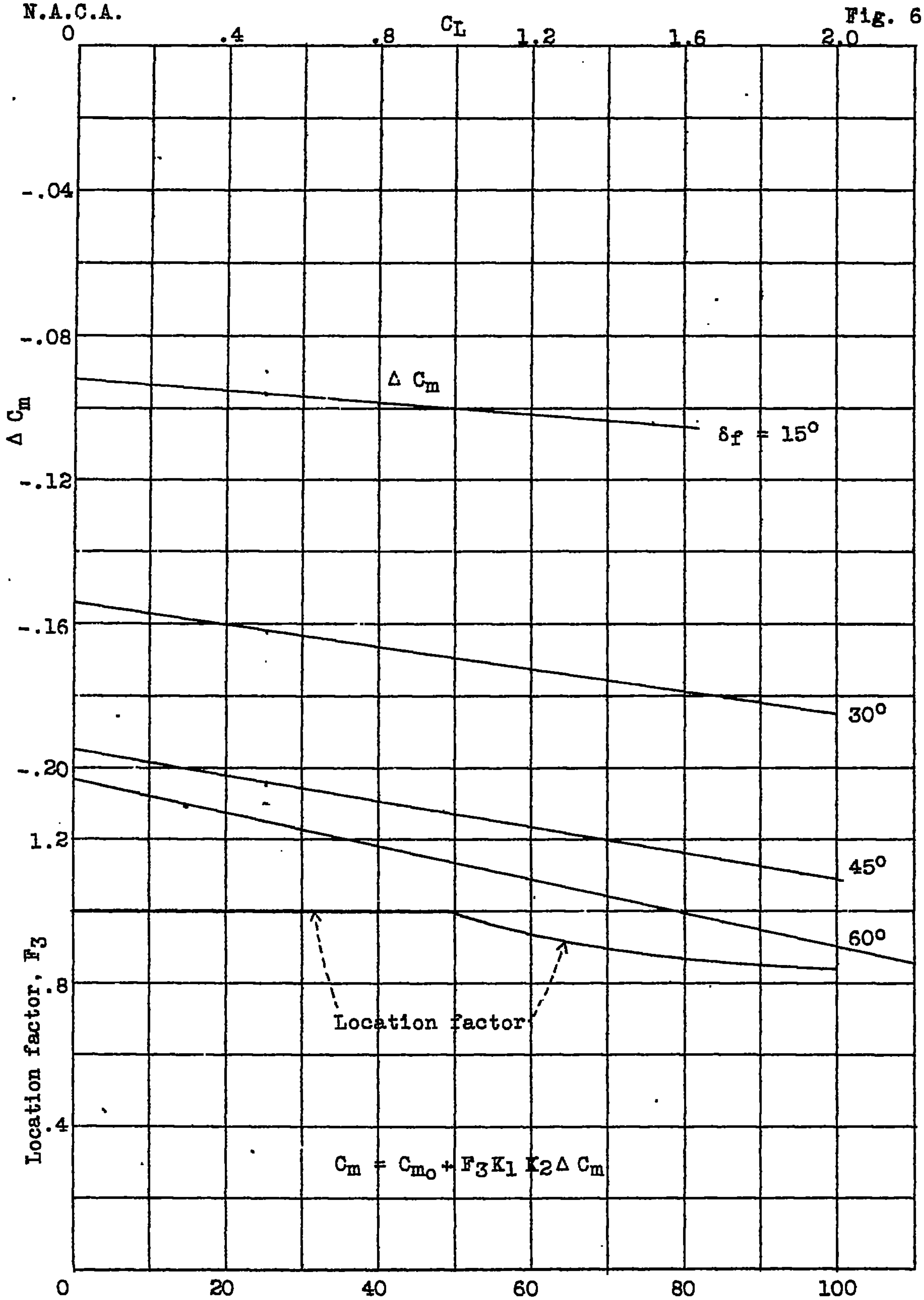


Figure 6.- Pitching-moment increments for ordinary flaps.

N.A.C.A. Fig. 7

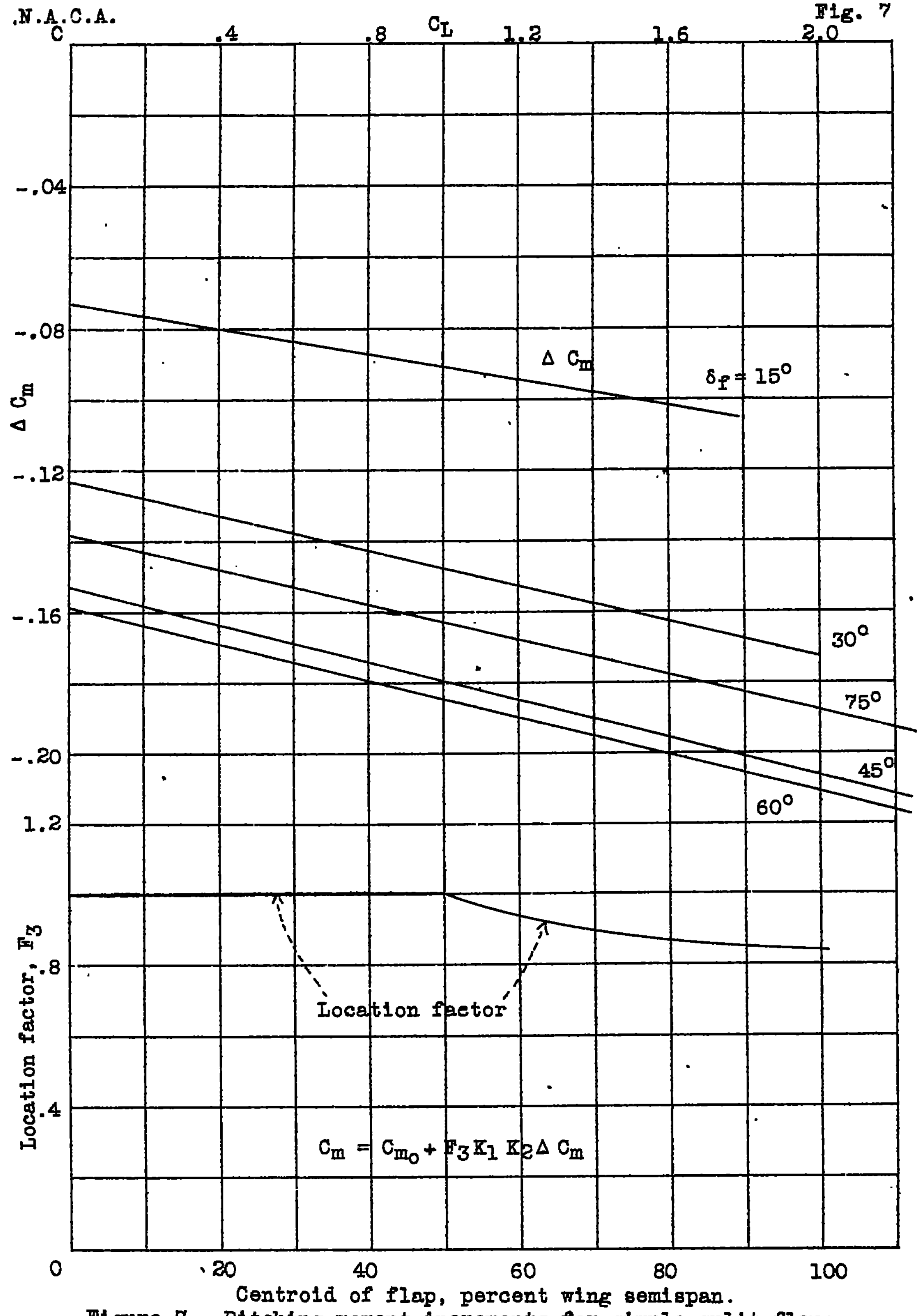


Figure 7.- Pitching-moment increments for simple split flaps.

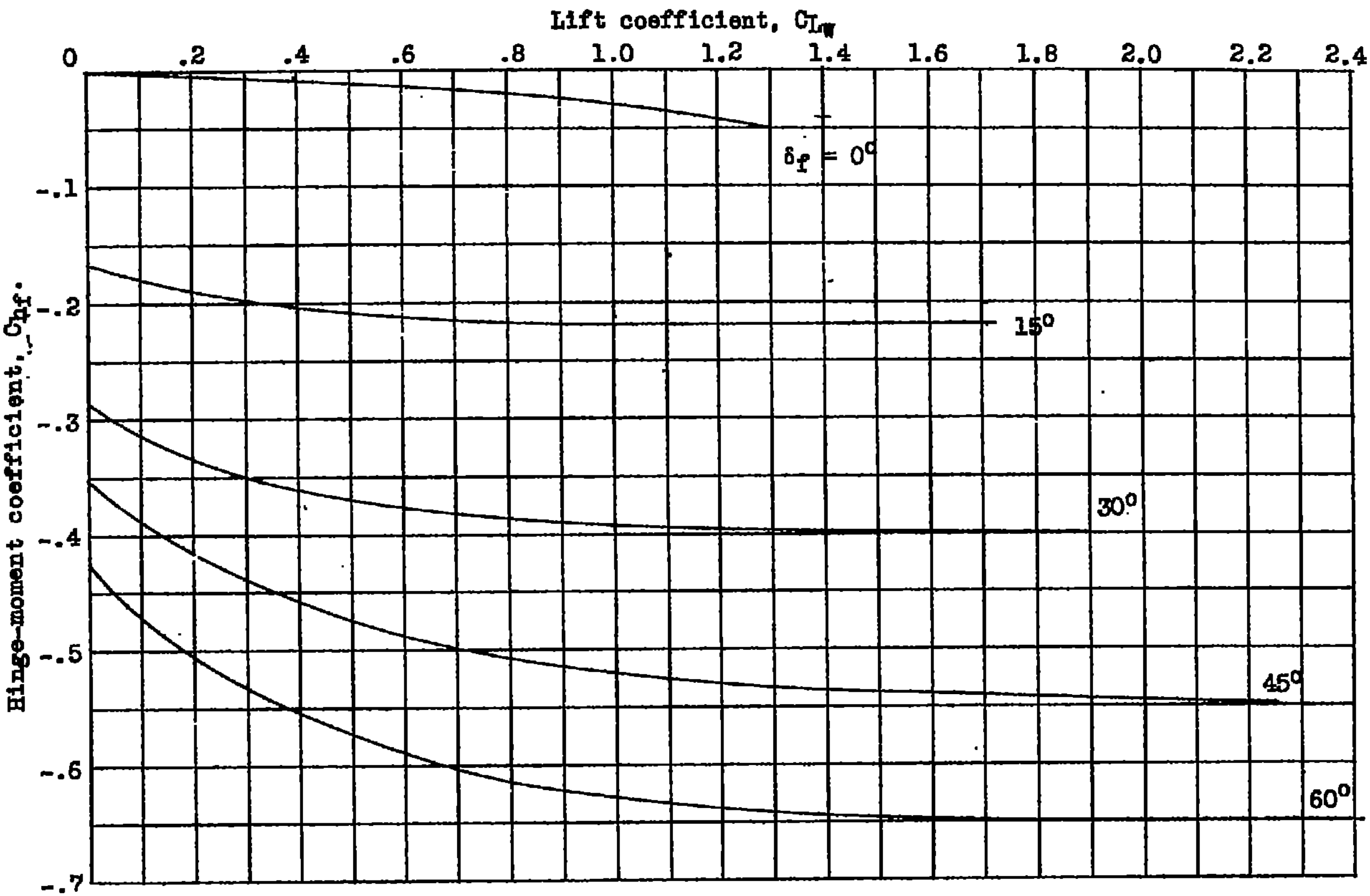


Figure 8.- Hinge-moment coefficients for ordinary and split flaps.

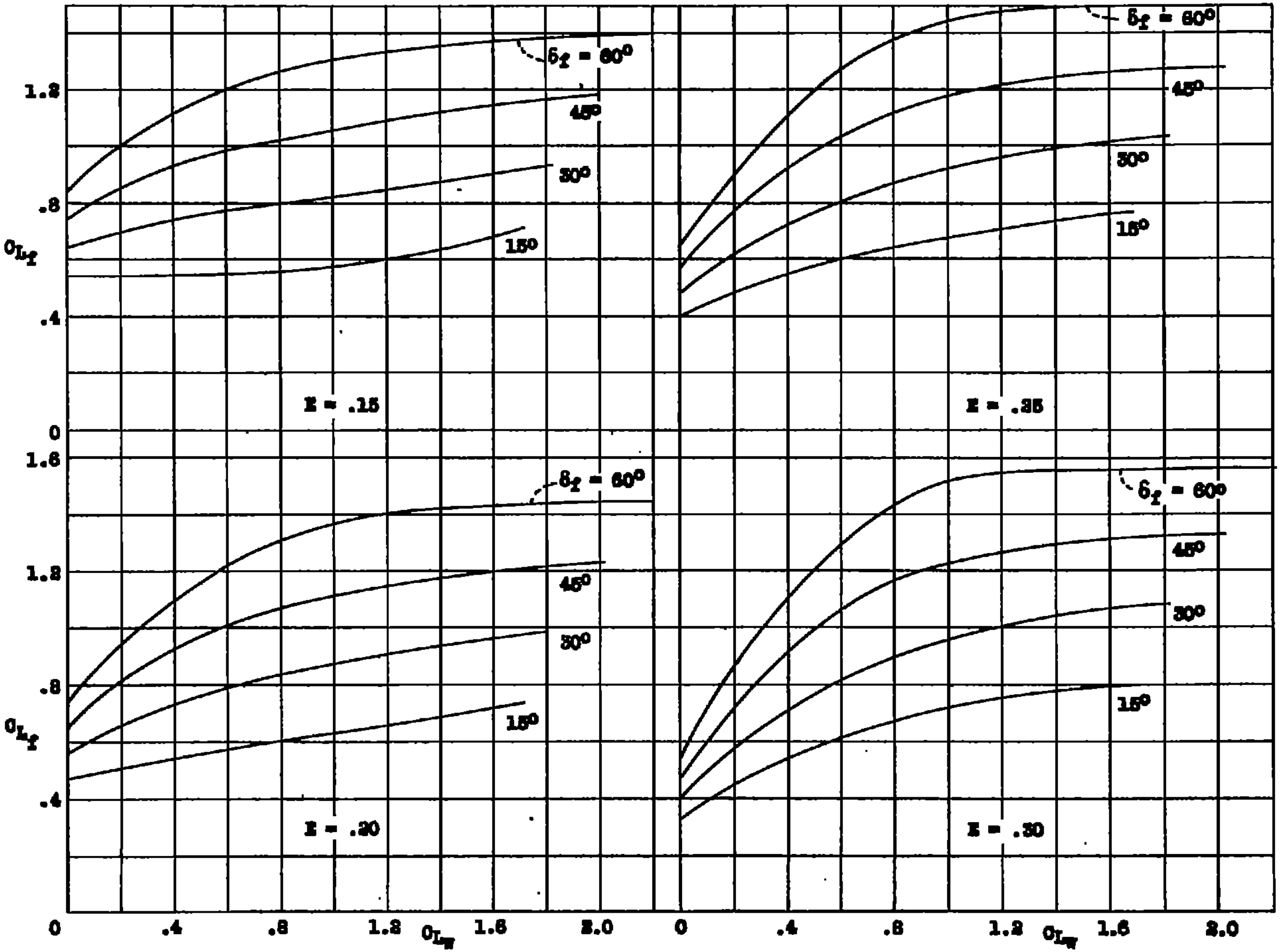


Figure 9.- Flap lift coefficients for ordinary and split flaps.

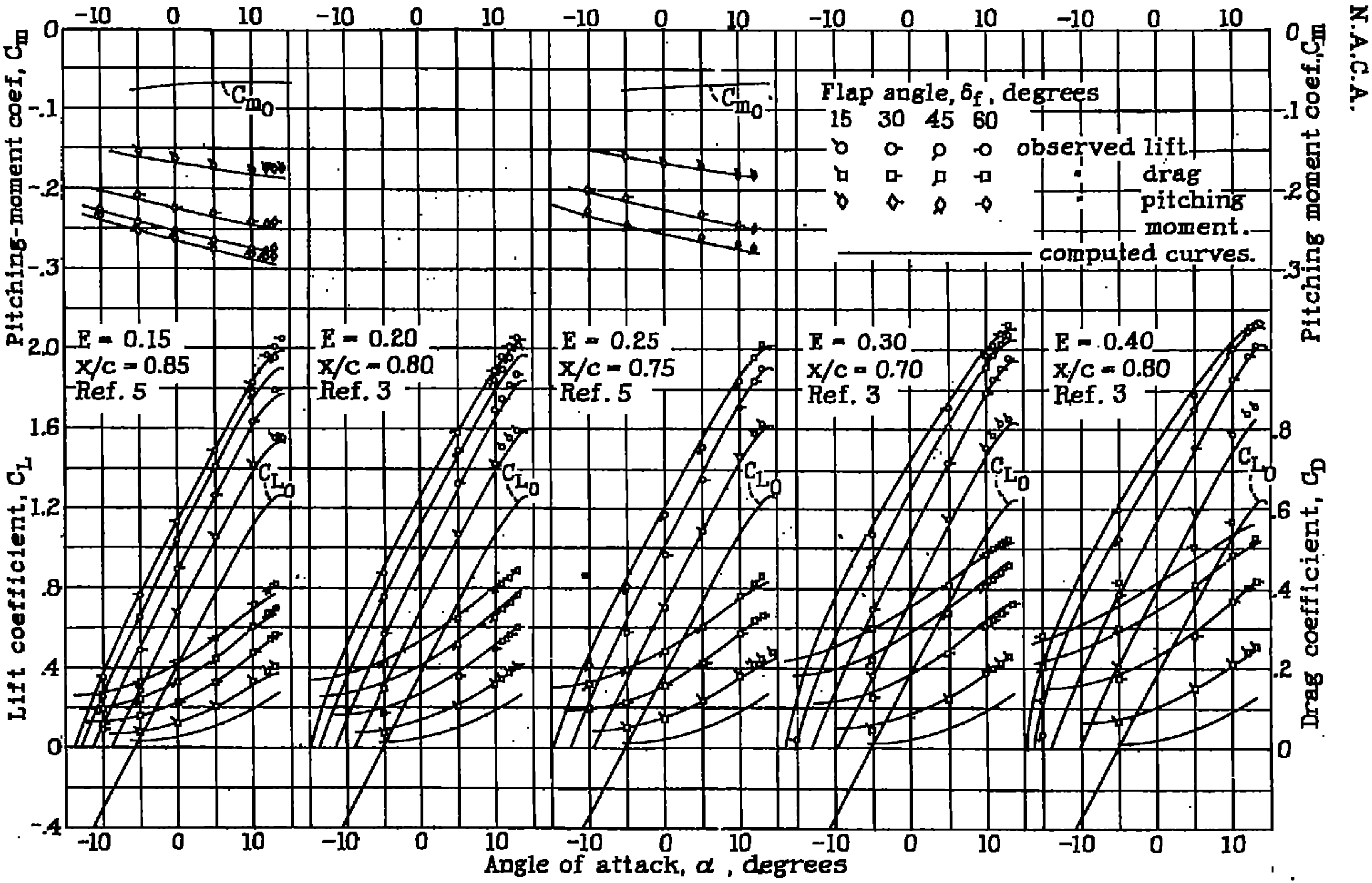


Figure 10.- Comparison of computed and observed characteristics for simple split flaps on a Clark Y wing.

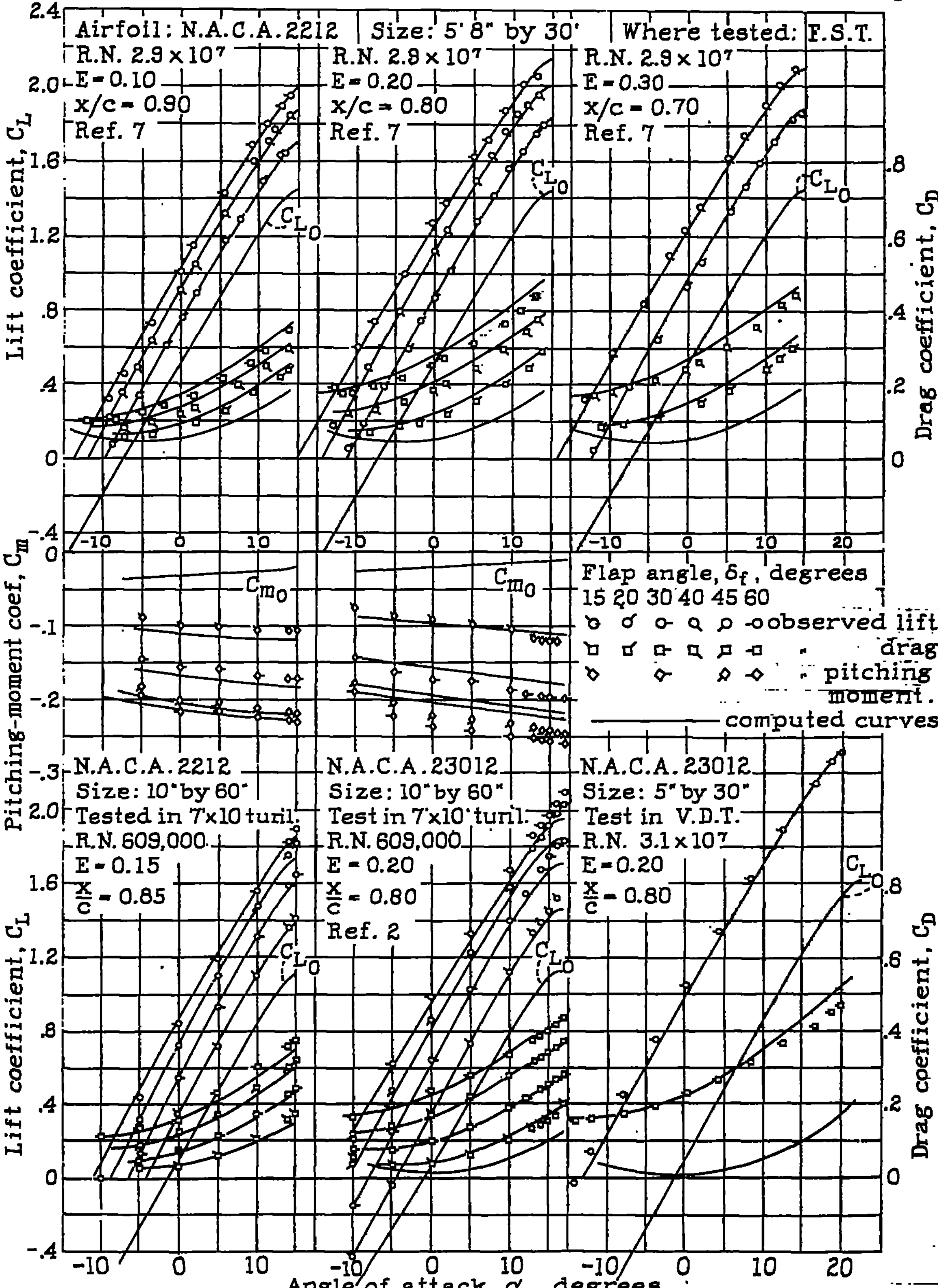


Figure 11.- Comparison of computed and observed characteristics for simple split flaps.

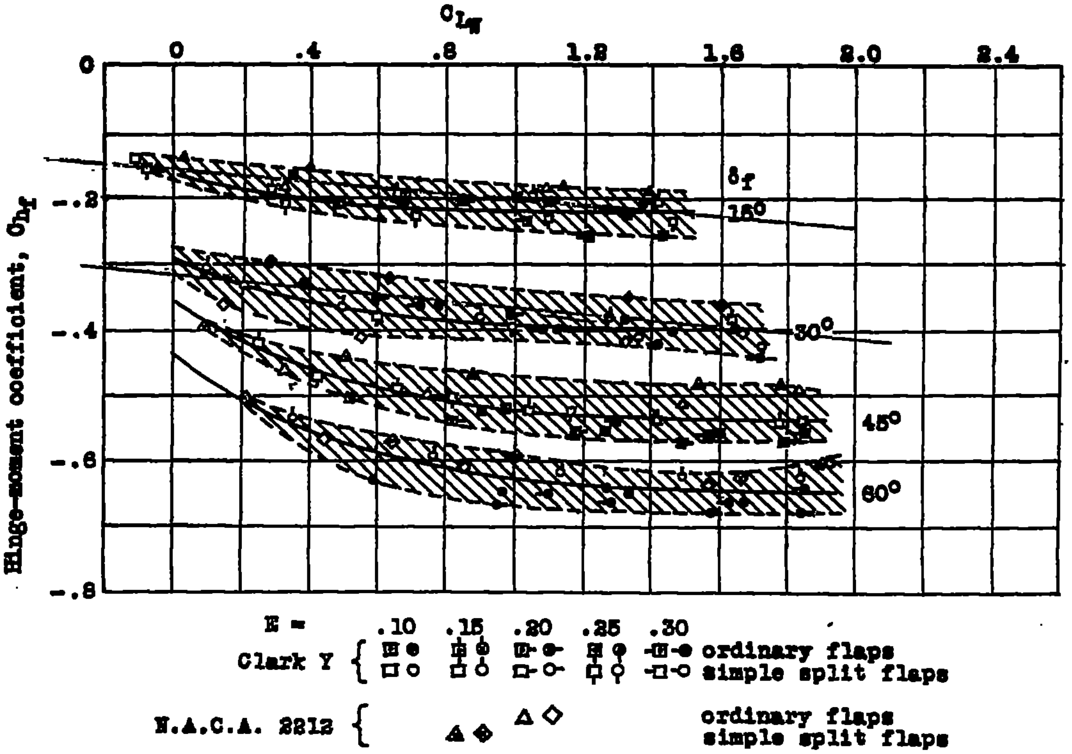


Figure 12. Comparison of hinge-moment coefficient for ordinary and split flaps.

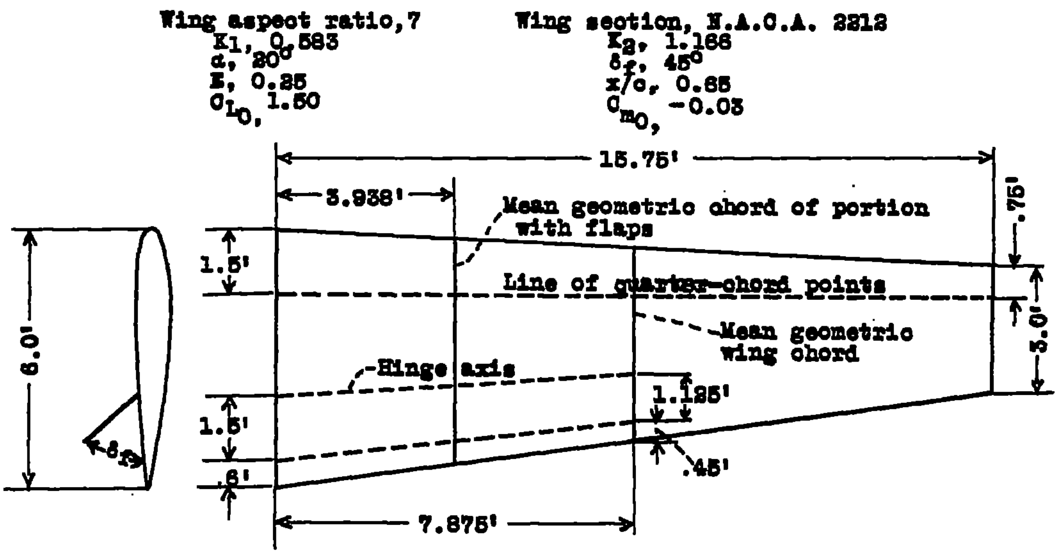


Figure 13.- Wing used in example.